SPACEPORT
ENGINEERING &
TECHNOLOGY

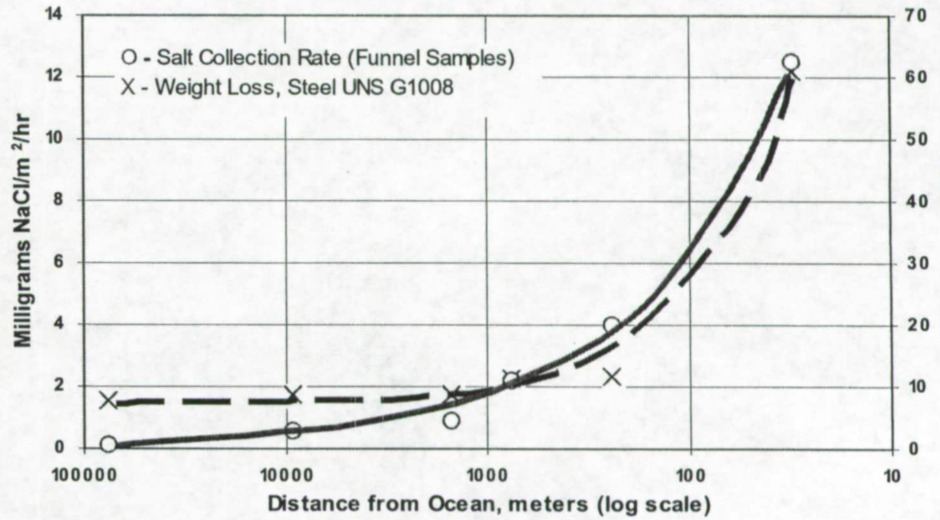
National Aeronautics and
Space Administration
John F. Kennedy Space Center

Outline

- Environment at KSC
- Corrosion @ KSC
- Material Evaluations at KSC
- Corrosion of Rebar in Concrete
- Functionality of Galvanic Liquid Applied Coating
- Experimental Design
- Data
- Conclusions

Corrosion at KSC

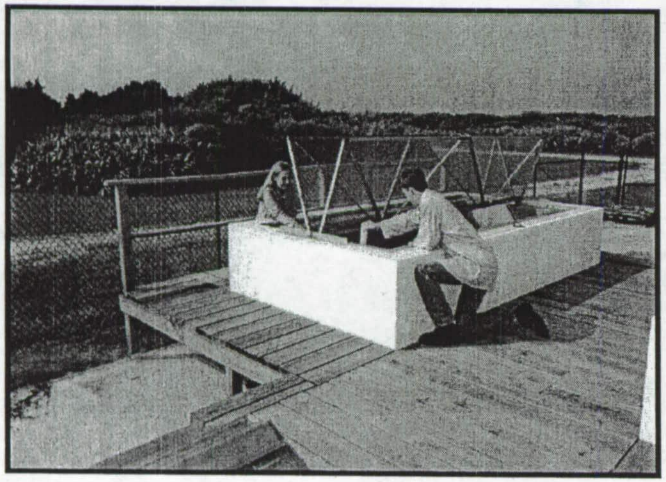
Location	Type Of Environment	µm/yr	Corrosion rate (a) mils/yr
Esquimalt, Vancouver Island, BC, Canada	Rural marine	13	0.5
Pittsburgh, PA	Industrial	30	1.2
Cleveland, OH	Industrial	38	1.5
Limon Bay, Panama, CZ	Tropical marine	61	2.4
East Chicago, IL	Industrial	84	3.3
Brazos River, TX	Industrial marine	94	3.7
Daytona Beach, FL	Marine	295	11.6
Pont Reyes, CA	Marine	500	19.7
Kure Beach, NC (80 ft. from ocean)	Marine	533	21
Galeta Point Beach, Panama CZ	Marine	686	27
Kennedy Space Center, FL (beach)	Marine	1070	42

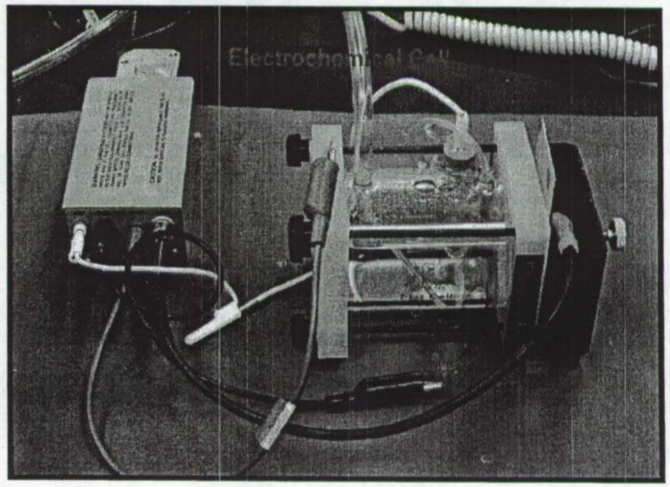


- **ASM documented this site as one of the most corrosive naturally occurring environments.**

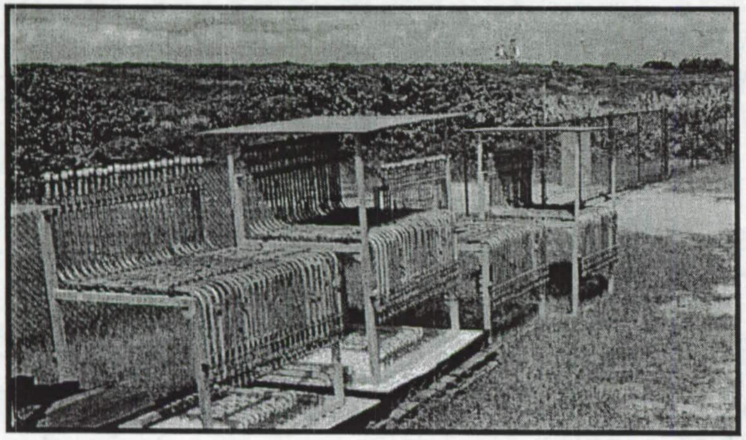
Corrosion Technology Testbed

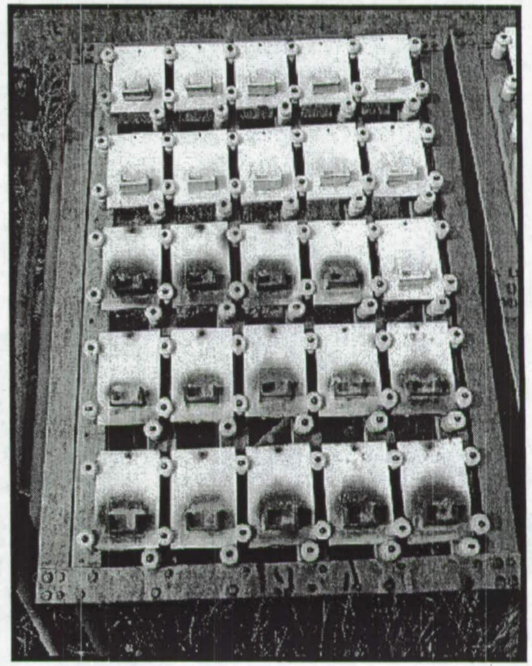
- Electrochemistry laboratory
- Accelerated corrosion equipment
- Coatings application laboratory
- Atmospheric exposure site
- Seawater immersion system

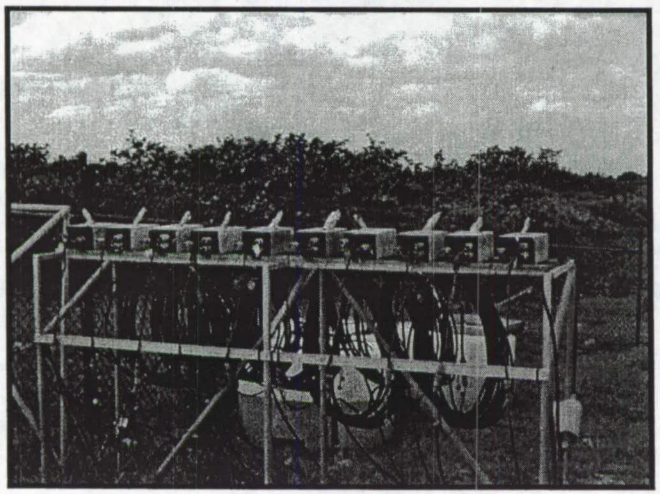




Materials Investigated at the NASA Corrosion Technology Testbed



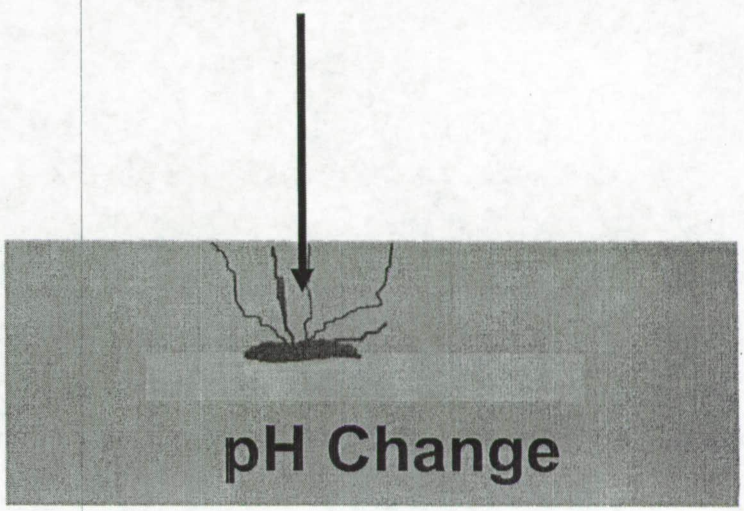




The Corrosion of Rebar in Concrete

- A passive film protects rebar from corrosion
- The passive film can be broken down by:
  - Carbonation of the concrete
  - Chloride attack
- Corrosion occurs

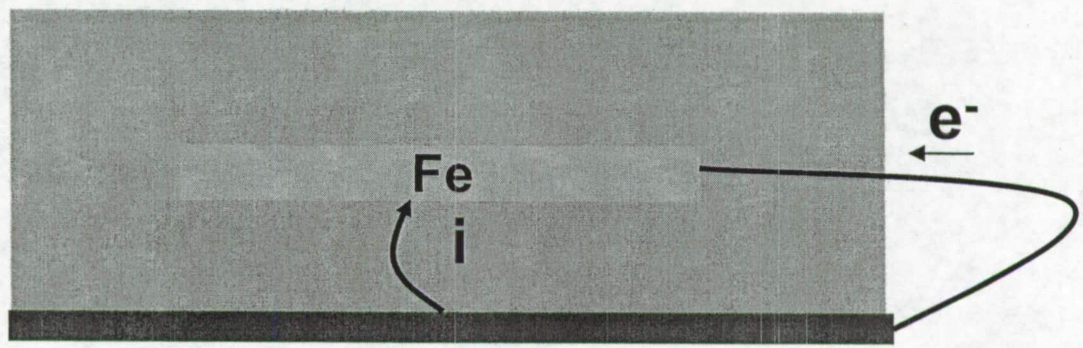
1) Chlorides 2) O_2 3) Moisture



$$2Fe \rightarrow 2Fe^{+2} + 4e^-$$

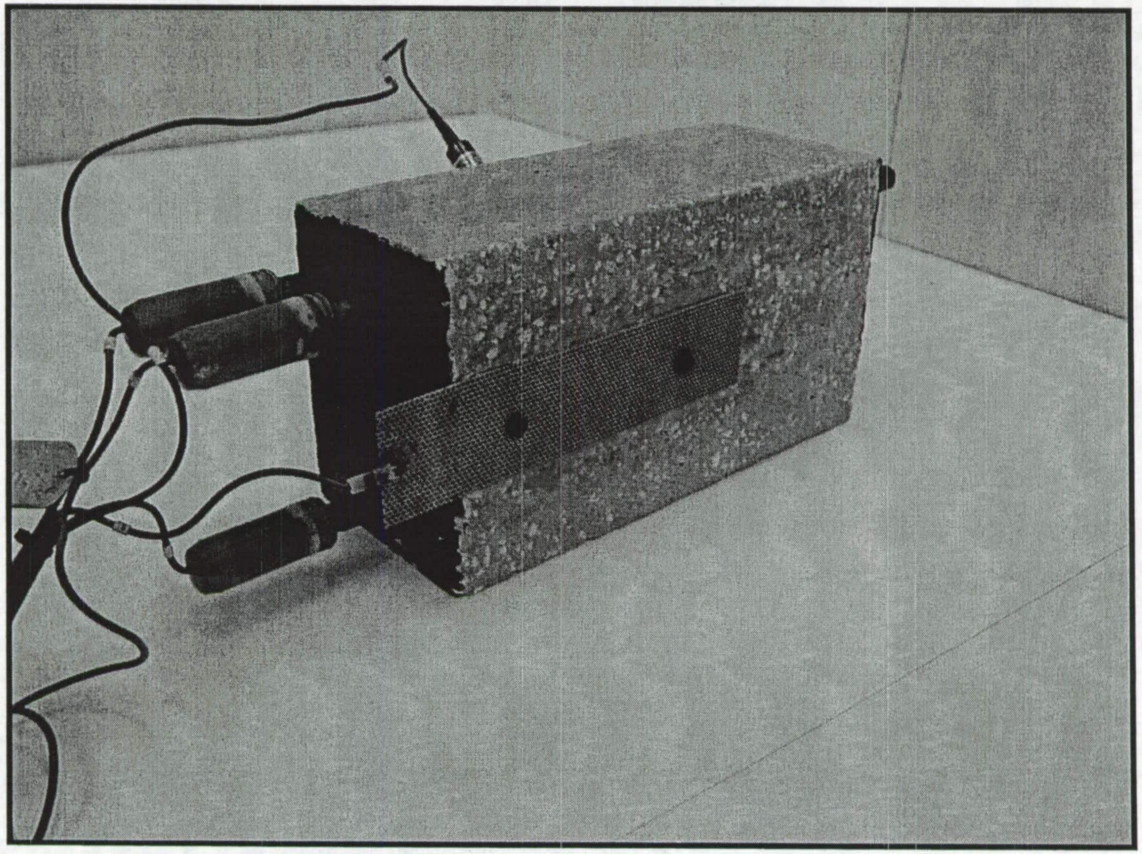
$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

The Protection of Rebar in Concrete with a Galvanic Liquid Applied Coating

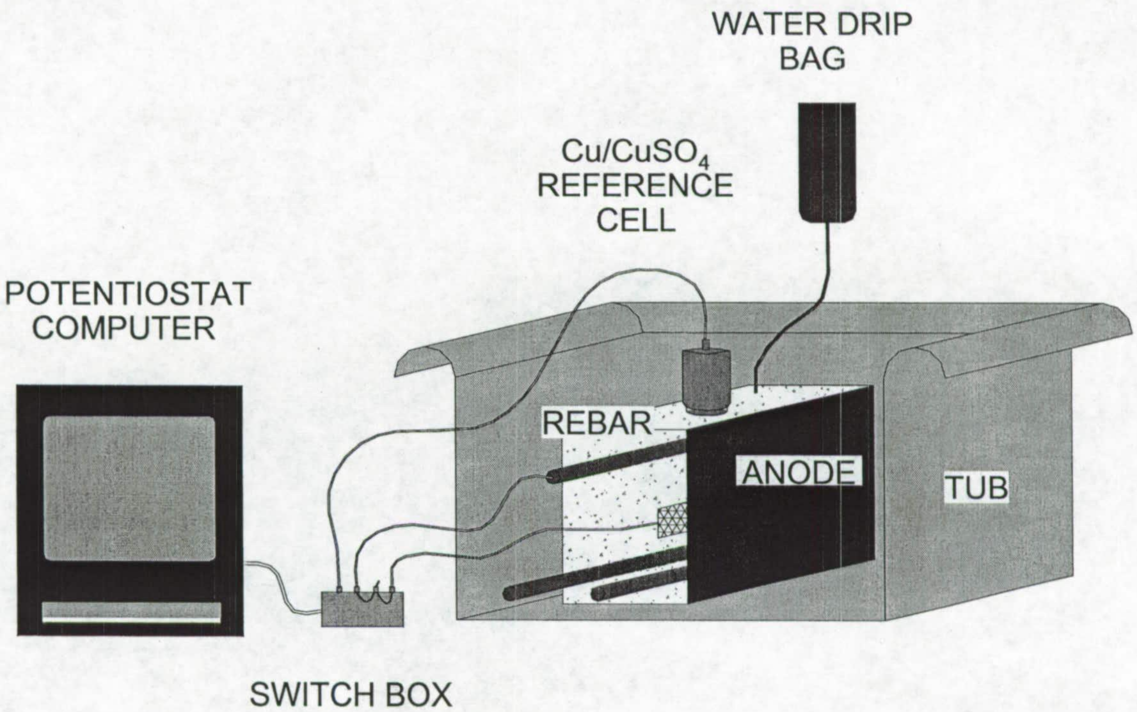


$$M \rightarrow M^{n+} + ne^{-}$$

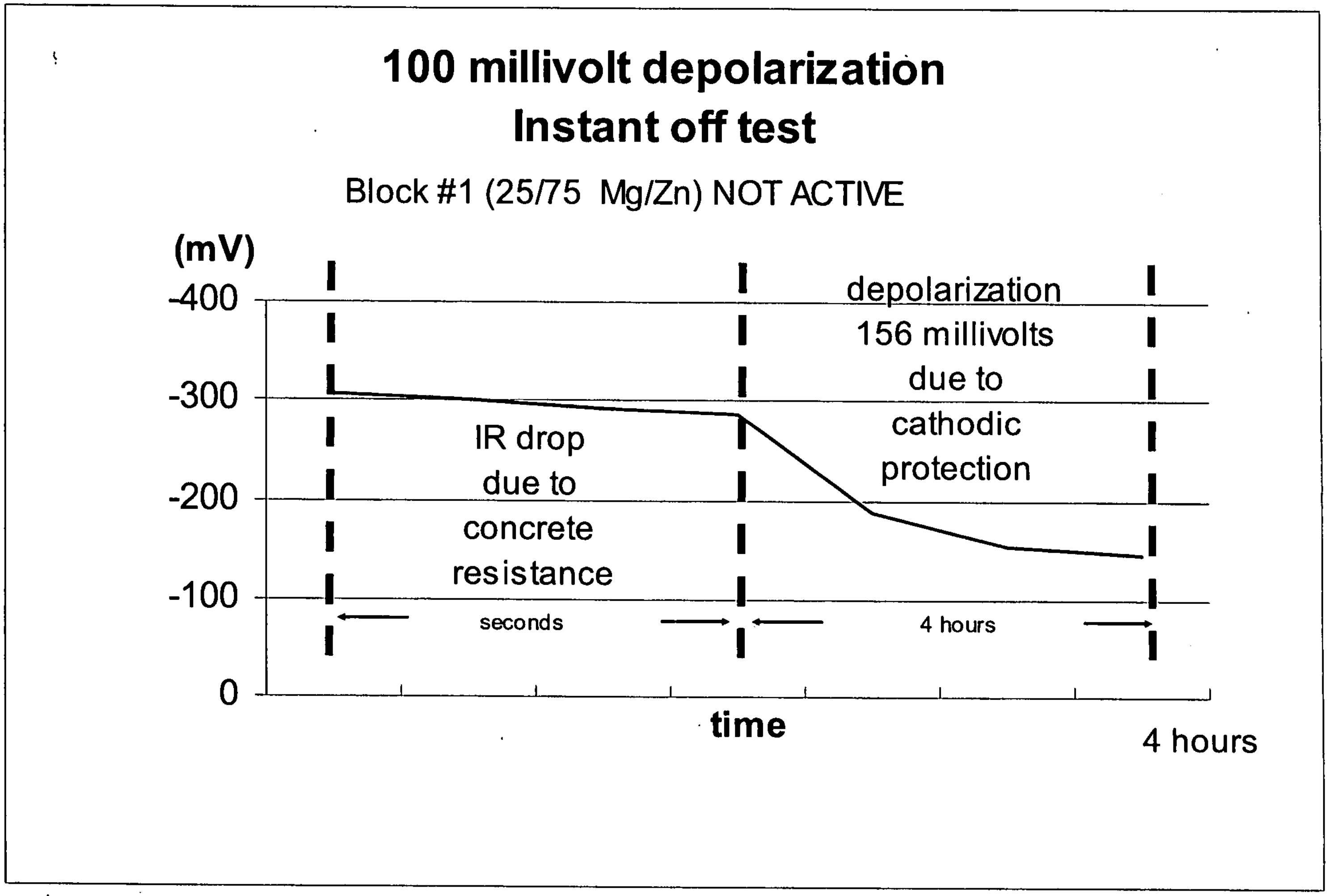
Experimental Test Blocks (ASTM G109 Modified)



Experimental Apparatus (Laboratory)



Depolarization Testing (NACE RP0290-2000)



Results of Depolarization Test (NACE RP0290-2000)

Mg/Zn	Active	Block #	Depolarization, mV
25/75	NO	1	156
0/100	YES	4	78
100/0	NO	6	35
0/100	NO	7	47
50/50	YES	9	28
25/75	YES	10	145

Electrochemical Measurements under Atmospheric Conditions

TEST PARAMETERS Phase I Designations				BEFORE RAIN		AFTER RAIN		CHANGES[1]		PROTECTION SUMMARY[2]	
Block #	Mg %	Zn %	Active[3]	I (uA)	V (mV)[4] Ag/AgCl-	I (uA)	V (mV)[4] Ag/AgCl-	uA	mV	Corrosion	Protection
1	25	75	No	0	-30	270	-260	270[5]	-230[5]	?	Good
3	0	100	Yes	na	-300	na	-330	na	-30[5]	Yes	na
4	0	100	Yes	400	-300	700	-350	300	-50[5]	?	Good
6	100	0	No	0	-30	5	-40	5	-10	No	Fair
7	0	100	No	0	-50	5	-130	5	-80[5]	?	Fair
8	50	50	No	5	-60	20	-100	15	-40[5]	No	Fair
9	50	50	Yes	0	-170	350	-350	350[5]	-180[5]	No	Good

1 Change in current and voltage occurs from time rain starts to about 0.7 days later.
2 *Protection* denotes a subjective evaluation of the current and voltage at the rebar, whether there is sufficient negative voltage and sufficient current to prevent rebar corrosion. The NACE standard, RP0169-96, was used as a guideline for determining protection (with a sacrificial coating in place) potential of the rebar.
3 *Active* denotes salt-ponded to induce corrosion.
4 Referenced to an Ag/AgCl- half cell (manufactured by Broadley James) at 199 mV vs. standard hydrogen electrode (SHE).
5 Sharp peak occurred after each rain.

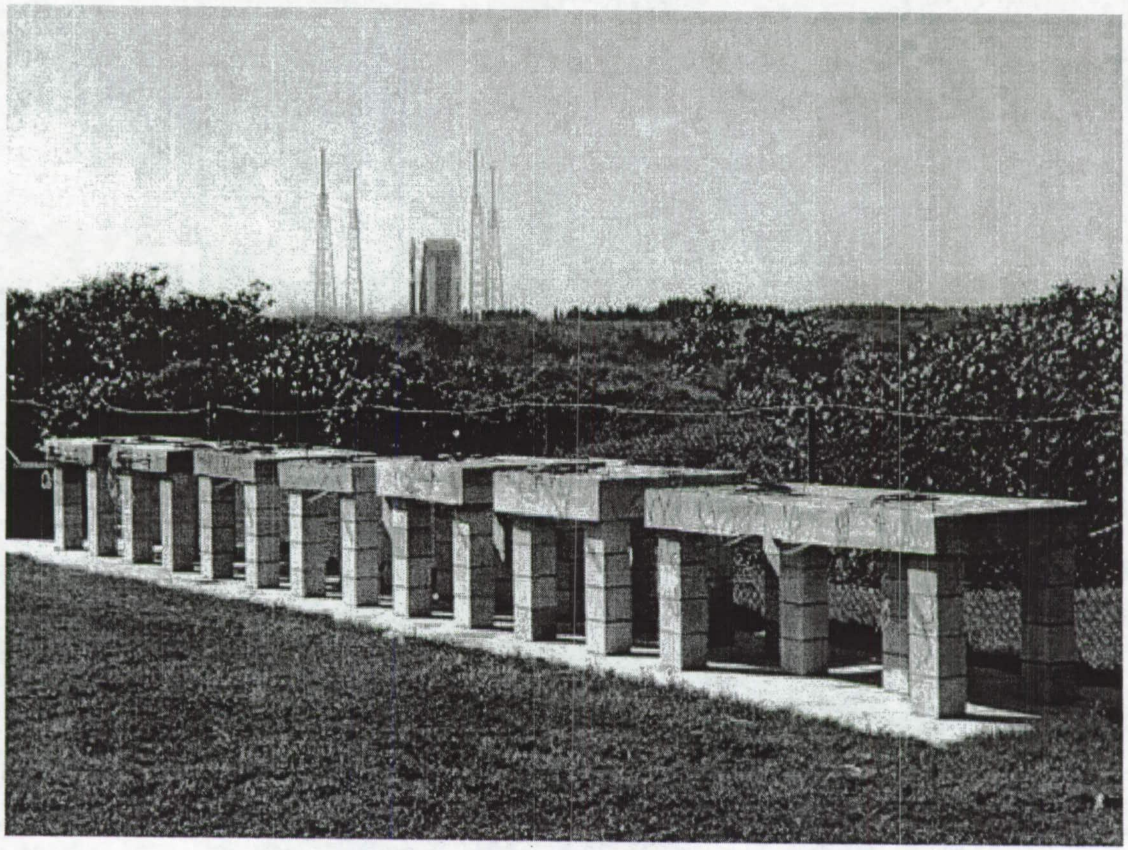
Recorded Potentials (New Formulation)

Location	Block #	Coating % Zn/Mg/In	Coating Dry Thickness	OCP- Rebar ($Ag/AgCl^-$)	Coating Potential ($Ag/AgCl^-$)	Rebar Polarized Potential ($Ag/AgCl^-$)
1	2	75/25/0	old	-193 mv	-0.725 v	-610 mv
2	10	75/25/0	38 mil	-213 mv	-1.25 v	-642 mv
3	14	75/25/0	38 mil	-267 mv	-1.23 v	-590 mv
4	15	75/25/0.2	39.5 mil	-254 mv	-1.28 v	-870 mv
5	16	75/25/0	35 mil	-150 mv	-1.23 v	-615 mv
6	17	75/25/0	38 mil	-282 mv	-1.25 v	-587 mv
7	18	75/25/0.2	37 mil	-299 mv	-1.29 v	-900 mv
8	19	Uncoated	0	-245 mv	n/a	-255 mv
9	20	75/25/$CuSO_4$	old	-212 mv	-0.385 v	-320 mv
10	24	75/25/0.2	34.5 mil	-343 mv	-1.27 v	-740 mv

Comparison of Measured Potentials

Block #	Potential vs. Ag/AgCl⁻ (mV)					
	Coating % Zn/Mg/In	OCP 7/2000	OCP 1/2002	OCP 6/2003	ΔE_{0-24}	Protection
2	75/25/0	-315	-193	-345	-30	Good Init. Perf.
10	75/25/0	n/a	-345	-375	n/a	no
14	75/25/0	-490	-383	-322	168	Fair
15	75/25/0.2	-345	-390	-390	-45	Corroding
16	75/25/0	-480	-274	-245	235	Good
17	75/25/0	-500	-324	-375	125	Good Init. Perf.
18	75/25/0.2	-270	-200	-82	188	Great
19	Uncoated	-350	-245	-380	30	Good Init. Perf.
20	75/25 ($CuSO_4$)	-343	-212	-182	161	Good
24	75/25/0.2	-470	-309	-272	198	Fair

Current / Future Work



Conclusions

- Blocks 18 and 20 met the criteria for cathodic protection according to the NACE RP0290 100 mV shift.
- Further Research is needed to conclude why two of the blocks are performing well, while the others have failed.
- The Galvanic Liquid Applied Coating works on ASTM G109 test blocks and meets the NACE criteria for protection.
- An investigation is proceeding to determine the effectiveness of the liquid applied coating to protect reinforced steel in larger structures.

NASA Corrosion Technology Testbed

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